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NOTCHED FATIGUE AND FRETTING FATIGUE LIFE OF TEXTURED TITANIUM.(U)
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NOTCHED FATIGUE AND FRETTING FATIGUE LIFE OF TEXTURED TITANIUM

ANTHONE ZARKADES
METALS RESEARCH DIVISION

May 1981

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ABSTRACT

The effect of texture, (0002) poles in the transverse direction, on the notched and fretting fatigue life of a Ti-4Al-4V alloy was examined. Notched fatigue and pin-loaded flat fretting fatigue specimens were tested at room temperature in the longitudinal and transverse directions and compared to smooth bar fatigue results. Fractured fretting fatigue specimens were examined with the scanning electron microscope. Indications are that no fretting or notch fatigue anisotropy exists for the transverse type texture and specimen orientations examined. However, as expected, a significant reduction of the fatigue life is displayed for specimens subjected to fretting fatigue.

INTRODUCTION

The anisotropic behavior of titanium and its alloys has been investigated and reported in a state-of-the-art report.[1] One of the most important discoveries in this area has been the significant improvement and control of fatigue life with proper utilization of crystallographic preferred orientation.[2,3] The transfusion of this research discovery could produce commercial applications which may ultimately improve helicopter reliability and efficiency.[4,5] However, fretting, a wear phenomenon, is brought about when two contacting surfaces experience small relative movement with resultant surface interface deterioration.[6] The process involves plastic deformation and the initiation of microcracks. The combined action of fretting and fatigue results in decreased fatigue strength and can be found in air, sea, and land vehicles and countless other engineering structures.

The National Materials Advisory Board has recommended that research studies be conducted to improve the understanding of fretting-initiated fatigue process with various material parameters including texture.[7] Since fretting fatigue is such an obvious problem, and it has been established that crystallographic preferred orientation or texturing can affect many material properties, it was the major concern of this program to determine if any fretting fatigue-texturing relationship existed. Titanium was selected for examination because of its affinity to texturing and its increasing utilization in rotary and fixed wing design applications.

MATERIAL AND TEST PROCEDURE

The material examined was a Ti-4Al-4V nominal composition alloy in 1.5-inch-thick plate form with a hardness of 25 HRC. Tensile properties, averaged for two tests, for the longitudinal and transverse specimen orientations[8] are given in Table 1 along with

Table 1. TENSILE PROPERTIES

Orientation	Yield Strength (psi) 0.1%	Yield Strength (psi) 0.2%	Tensile Strength (psi)	Elon. (%)	E (psi)
Longitudinal	96,550	99,950	113,150	20.3	16.4×10^6
Transverse	115,300	117,750	123,250	18.5	18.7×10^6

CHEMICAL ANALYSES (Weight Percent)

Al	V	O	H	N
4.18	4.11	0.134	0.007	0.018

1. LARSON, F. R., and ZARKADES, A. *Properties of Textured Titanium Alloys.* Metals and Ceramics Information Center, MCIC 74-20, June 1974.
2. ZARKADES, A., and LARSON, F. R. *Effect of Texture on Some Properties of Titanium.* Army Materials and Mechanics Research Center, AMMRC TN 73-7, May 1973.
3. SPURR, W. F., et al. *Standardization of Ti-6Al-4V Processing Conditions.* Boeing Commercial Airplane Company, AF33615-75-C-5176, December 1976.
4. LUDTKA, G. M. *HLH/ATC Titanium Alloy 6Al-4V Leading Edge Material.* Boeing Vertol Company, Report 7301-10246-1, September 1973.
5. KESSLER, H. D. *Technology Forecast.* ASM Metal Progress, v. 111, no. 1, January 1977, p. 36.
6. WATERHOUSE, R. B. *Fretting Corrosion.* Pergamon Press, New York, 1972.
7. *Control of Fretting Fatigue.* National Materials Advisory Board Committee on Control of Fretting-Initiated Fatigue, NMAB-333, 1977.
8. ZARKADES, A., and LARSON, F. R. *Effect of Texture on the Charpy Impact Energy of Some Titanium Alloy Plate.* Army Materials and Mechanics Research Center, AMMRC TR 72-21, June 1972.

the chemical analyses. Variation of other important properties with specimen orientation was reported for the same material in previous reports.[2,8] It was established that anisotropy relative to toughness, creep stress rupture, stress corrosion cracking, and fatigue does exist. The texture is illustrated in Figure 1 and indicates a very high intensity of the (0002) poles fifteen degrees from the transverse direction.

The fretting fatigue specimen geometry was identical to that used in a Boeing-AMMRC cooperative study and simulates the fundamental and common pin-joint utilized in many structures and vehicles.[9] The pin-loaded flat type specimen is shown in Figure 2. Specimens were machined from the rolling and transverse directions as indicated in Figure 3, and had a theoretical stress concentration factor of $K_t = 2.28$. AISI 4340 steel (40-42 HRC) shoulder screws, nominal 3/8" × 1-3/4", were utilized as pins. New pins were used with each specimen.

Notch fatigue specimen geometry with a theoretical stress concentration of $K_t = 4.50$, which is approximately twice that of the fretting sample, is shown in Figure 4. Both longitudinal and transverse specimens were tested at room temperature at a frequency of 1800 rpm and a stress ratio, R = 0.10.

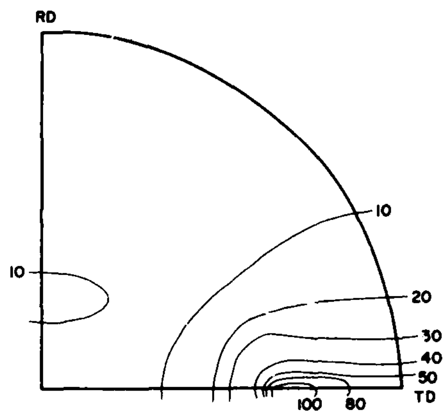

Figure 1. (0002) Pole figure of 4Al-4V-H8839.

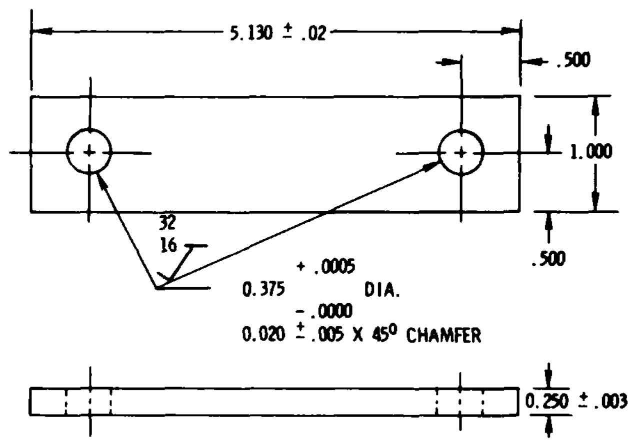

Figure 2. Pin-ended fretting fatigue specimen.

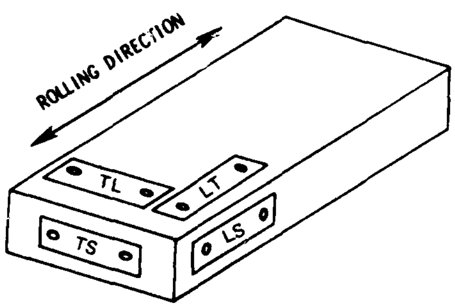

Figure 3. Schematic of specimen orientation.

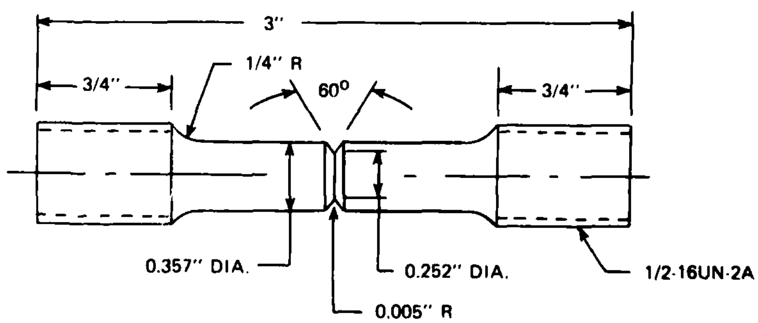

Figure 4. Notch fatigue specimen.

9. *HLH/ATC Titanium Materials Evaluation Program.* Boeing Company, Vertol Division, Test Results Report T301-10168-1, March 1973.

DISCUSSION

Fatigue results are plotted as conventional stress-cycles, S/N, curves. The transverse results, Figure 5a, show a significant decrease in fretting fatigue strength when compared to the smooth, or unfretted, strength of the material as previously reported.[1,2] The strength reduction ranges from 55 percent at the high stress-low life area to 75 percent at 10^7 cycles. In Figure 5b the longitudinal fretting specimens show a 75 percent degradation of fatigue life along the entire curve. In fact, the reduction of fatigue life due to fretting is even more severe than that imposed by the notched specimens with twice the stress concentration. Further examination of data reveals no anisotropy with regard to LT, LS, or TS, TL orientation. The isotropic behavior of the notched and fretting fatigue life is clearly established and is especially evident when compared to the anisotropic behavior of the smooth fatigue results.[1,2] This insensitivity of the notched and fretting fatigue life to texture indicates, as previously reported, that the effect of texture is demonstrated as an influence upon crack nucleation rather than crack propagation.

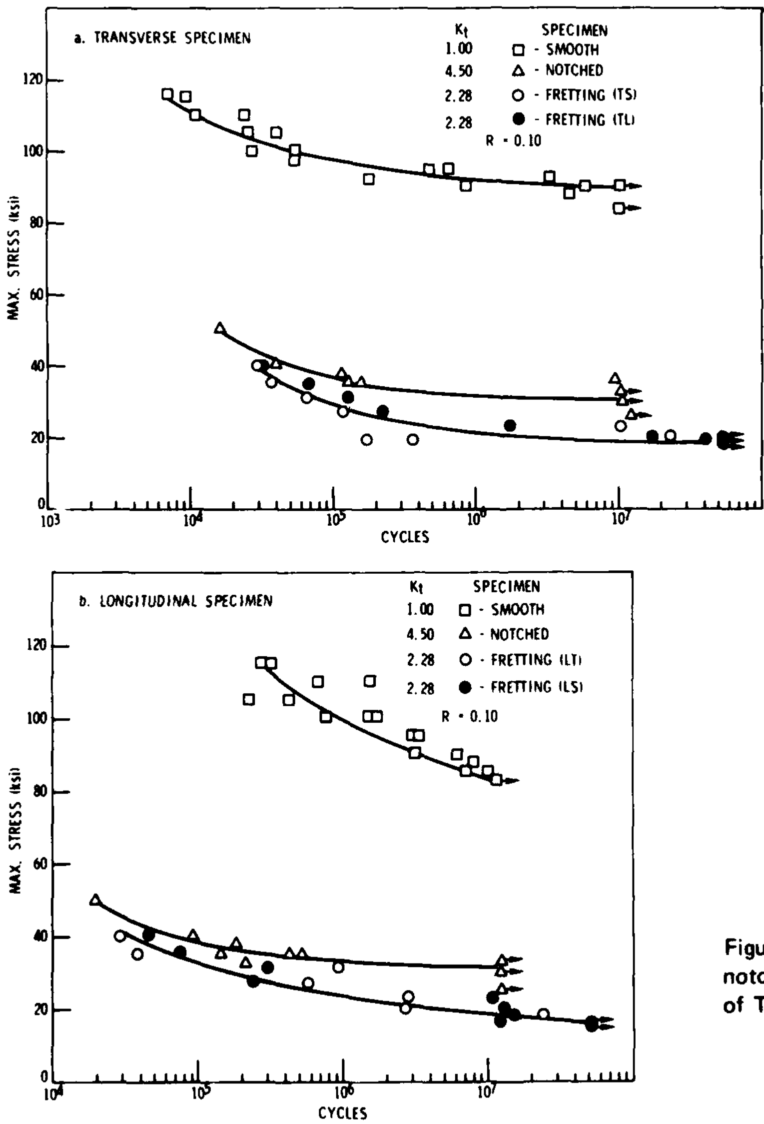

Figure 5. Comparison of fretting, notched, and smooth fatigue life of Ti-4Al-4V.

Fractured test specimens representative of those examined are shown in Figure 6a. Without exception, fracture occurred at one hole in the reduced area section. One reliable method of determining if failure is initiated by fretting is the observation of tongue and chip of the material on the fractured surface.[6] This feature, enlarged in Figure 6b is a result of fatigue cracks which initially run obliquely to the fretting area and then continue to propagate at right angles to the stress directions.[6]

Examination of the pin, pinhole, and fracture surface was conducted on the scanning electron microscope (SEM). Fracture origin sites were found to be inside the pinhole and occur at either one site, Figure 7a, or multiple sites as in Figure 7b. Closer examination of the pinhole area revealed characteristic fretting fatigue surface damage. Cavities or scars, as shown in Figure 8, were found with fatigue cracks emanating or passing through the damaged area.

The typical condition of the steel pins taken from the fractured specimens is shown in Figure 9a. Examination of the damaged area revealed fretting debris and material in plate form as shown in Figure 9b. This exfoliation is characteristic of fretting, especially for a sphere on a flat.

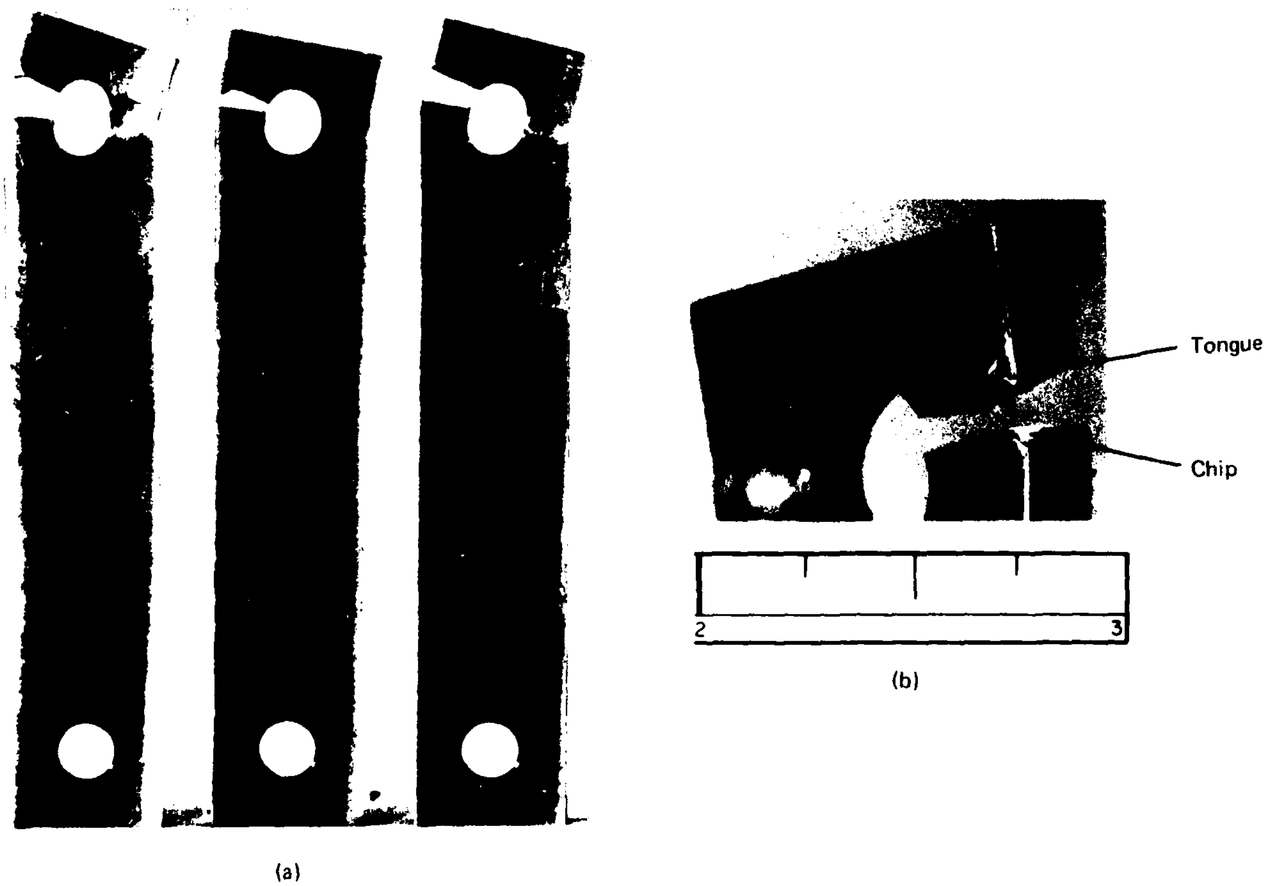

Figure 6. LT fretting fatigue specimens (a) showing enlargement of fracture surface (b).

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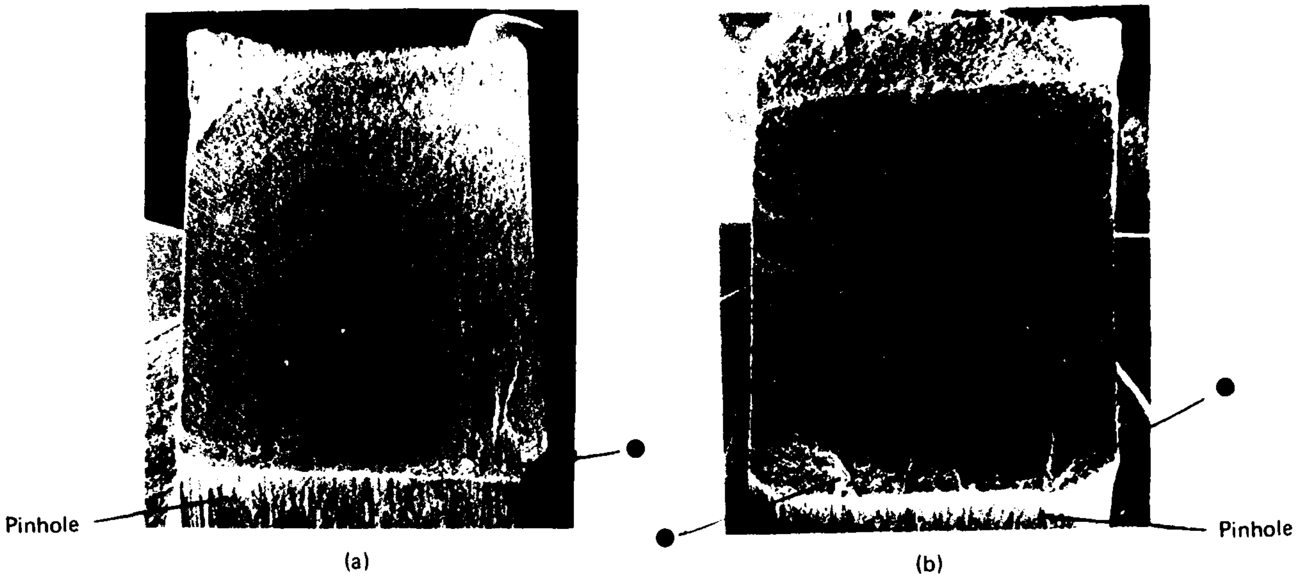
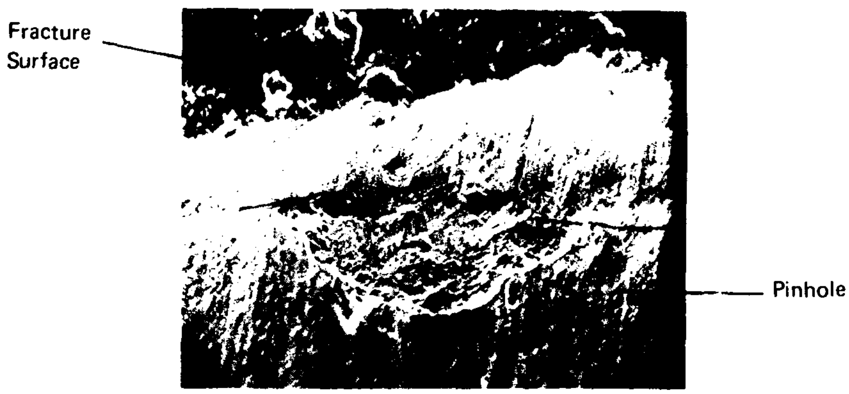


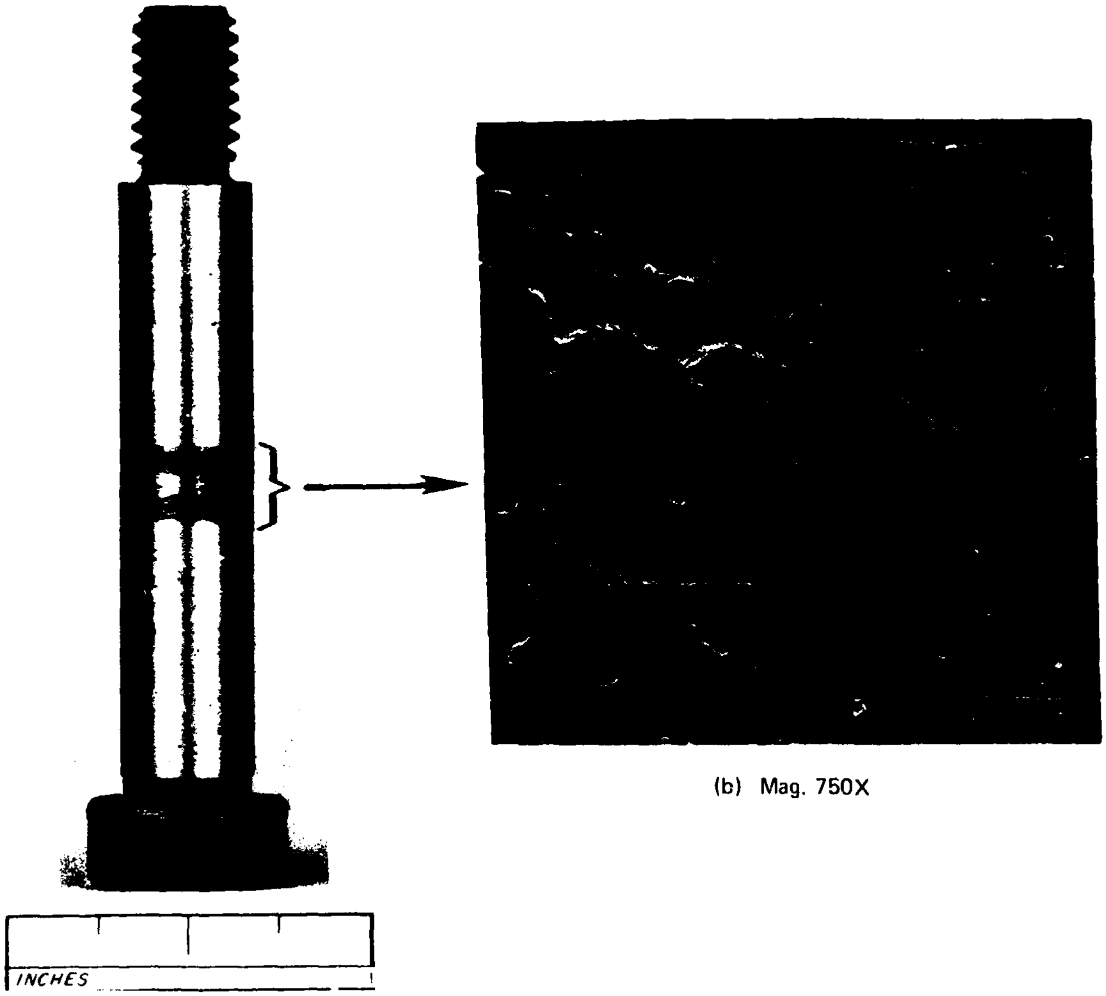
Figure 7. ● Fracture origin sites. Mag. 8.5X



a. Mag. 650X

b. Mag. 1300X

Figure 8. Fatigue cracks emanating or passing through fretting damage in pinhole.



(a)

(b) Mag. 750X

Figure 9. Steel shoulder screw pin.

CONCLUSIONS

Results have indicated that the effect of crystallographic preferred orientation on the notched specimens and fretting fatigue life is minimal. Round notched fatigue and flat titanium specimens, steel pin loaded, were tested in the longitudinal and transverse directions. No anisotropy was observed. However, comparison of fretted with unfretted samples indicated a significant strength reduction factor of four or a 75 percent reduction of the smooth fatigue life. It is clear there is a serious reduction of strength of titanium from fretting when combined with fatigue, and appropriate action needs to be taken to minimize the deleterious condition by improved design, lubrication, surface treatments, etc.

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